Electric Power Systems Research 124 (2015) 160–172

Contents lists available at ScienceDirect

Electric Power Systems Research

journal homepage: www.elsevier.com/locate/epsr

Transient stability enhancement by bridge type fault current limiter considering coordination with optimal reclosing of circuit breakers

Mohammad Ashraf Hossain Sadi*, Mohd. Hasan Ali

Department of Electrical and Computer Engineering, University of Memphis, 3815 Central Avenue, Memphis, TN 38152, USA

ARTICLE INFO

Article history:
Received 11 November 2014
Received in revised form 18 February 2015
Accepted 16 March 2015
Available online 2 April 2015

Keywords:
Bridge type fault current limiter (BFCL)
DC resistive fault current limiter (RFCL)
Optimal reclosing
Thyristor controlled series capacitor (TCSC)
Transient stability
Total kinetic energy (TKE)

ABSTRACT

This paper proposes the coordinated operation of the bridge type fault current limiter (BFCL) and optimal reclosing of circuit breakers to enhance the transient stability of a multi-machine power system. The transient stability performance of the proposed method is compared with that of the thyristor controlled series capacitor (TCSC) and the dc resistive fault current limiter (RFCL) considering the same optimal reclosing technique. The total kinetic energy (TKE) of the generators in the system is used to determine the transient stability enhancement index. Also, the critical clearing time has been presented as a stability limit. Simulations are performed by using the Matlab/Simulink software. Simulation results for both permanent and temporary faults at different points in the IEEE 30 bus power system and single-machine power system indicate that the coordinated operation of the BFCL and optimal reclosing of circuit breakers can enhance the transient stability of the system well. Also, the performance of the proposed method is better than that of the TCSC and RFCL considering the optimal reclosing technique.

1. Introduction

Transient stability refers to the ability of a power system to regain its stability following sudden and severe disturbances in the system [1]. In case of faults on the transmission lines, the circuit breakers open to protect the healthy section of the power network, and then reclose again after a fixed time interval provided that the fault arc has been deionized, in order to maintain continuity of power [1].

A conventional reclosing technique depicts the reclosing of circuit breakers after a prescribed time period, when the arc between the fixed contact and moving contact might or might not persist. However, if the arc persists, especially in case of a permanent fault, then the circuit breaker will not be able to reclose successfully and will sectionalize the system, which is an indication of the unstable state of the system. Since transient stability is also dependent on the generator state of reclosing, to maintain the synchronism and enhance the transient stability we have to find out an optimal reclosing time when reclosing of the circuit breakers will enhance the transient stability of the system effectively [1]. Optimal reclosing of circuit breakers is a proven method [2–5] for improving the transient stability of power system and according to the literature, optimal reclosing of circuit breakers works better than the conventional reclosing of the circuit breakers. But to the best of our knowledge, there is no work concentrating the combined effect of BFCL and optimal reclosing of circuit breakers on the transient stability of multi-machine power systems.

There are several methods for enhancing the transient stability of power systems. Among the stability enhancement methods, the braking resistor [6,7], Flexible AC Transmission Systems (FACTS) devices [8,9], Superconducting Fault Current Limiter (SFCL) [2], Static VAR Compensator (SVC) [3,9], Superconducting Magnetic Energy Storage (SMES) [4,5], etc., are popular and getting more applications day by day. Braking resistor is one of the most efficient and widely used control methods to improve the transient stability of power grid system. It is a dummy load connected in parallel with the synchronous generator of a power system. However, for application of braking resistor, a step down transformer should have to be connected to the generator terminal and that increases the cost of its application. FACTS devices including SVC have a number of applications including transient stability and some of them have specific operation too. Few FACTS devices can only control active power and few of them can control reactive power only. However, there are FACTS devices which can control both active and reactive powers. But the application of those FACTS devices will incur more cost in the power system because of their complex structure and control system. Like other FACTS devices, SVC is a reactive power controlling device which has indirect effect on controlling

* Corresponding author. Tel.: +1 901 335 8245; fax: +1 901 678 5469.
E-mail address: masadi@memphis.edu (M.A.H. Sadi).

http://dx.doi.org/10.1016/j.epsr.2015.03.011
0378-7796/

the active power of the power system as well as on the transient stability of the power system. SFCL is an effective active power controlling device which has tremendous effect in improving the transient stability of the power system. But it requires cooling system to maintain superconductivity. Therefore, its application also incurs a lot of cost. Similarly, SMES is an active and reactive power controlling device but it is a costly device too.

In power systems, fault current limiters (FCLs) are used to reduce the magnitude of current during a fault in the network [10,11]. FCLs introduce fixed impedances in the system in the event of faults and thus reduce the effect of high fault current level. In this way, they improve the transient stability of the system. Among the FCLs, the BFCL [10–12] is getting more popularity because of its simple structure, commercial application viability and cost effectiveness.

This work proposes the combined operation of BFCL and optimal reclosing of circuit breakers to enhance the transient stability of the multi-machine power networks, and this is the original contribution of this work. The BFCL is a series connected cost effective active power compensating device which overcomes the cost and application drawbacks of the auxiliary devices mentioned earlier. On the other hand, the total kinetic energy based optimal reclosing of circuit breakers is able to improve the stability of power system [2,3,5]. Also, the optimal reclosing technique for circuit breakers works better than the conventional reclosing of circuit breakers [2,3,5]. But to the best of our knowledge, there is no work available in the literature about the coordinated operation of BFCL and optimal reclosing of circuit breakers for power system transient stability enhancement and this is the originality of this work. This is to note here that, the BFCL was applied in improving the fault ride through capability of wind generator system [10,11,13]. Also, single machine system was used to check the performance of the BFCL [10,11,13]. To the best of our knowledge, there is no report available on the BFCL application to the transient stability improvement of multi-machine power systems. Therefore, this work showed the effectiveness of the proposed methodology in case of a large power network, i.e., the IEEE 30 bus power system [14,15]. In this work, we also presented the performance of the proposed methodology in single-machine power system.

For power system engineers and researchers, reactive power compensation is an important issue [1]. Reactive power generation is the inherent nature of the power system and it cannot be avoided. Moreover, in the smart grid system, more distributed generators are getting involved along with the traditional synchronous generators. So, reactive power compensation becomes a vital part in power system stability improvement. The Thyristor Controlled Series Capacitor (TCSC) [9] is a popular reactive power compensating FACTS device with less controller complexity and better performance [9]. It has the ability to improve the transient stability of the power systems [9].

The DC resistive fault current limiter (RFCL) implements the concept of both the rectifier type FCL and resistive type SFCL [16–18]. It works as a resistive type SFCL during the fault condition and works as a rectifier type FCL in the normal operating condition. Thus in this operating scheme, it avoids the ac current components as well as the ac losses and improve the stability of the power systems.

In this work, in order to see the effectiveness of the proposed BFCL and optimal reclosing of circuit breakers in improving the transient stability of the multi-machine power systems, its performance is compared with that of the TCSC and RFCL considering optimal reclosing of circuit breakers, and this is another salient feature of this work. For optimal reclosing of circuit breakers, we considered the total kinetic energy based optimal reclosing of circuit breakers [2,3]. Although the BFCL and RFCL are active power compensating devices and the TCSC is a reactive power compensating device, but all of them are connected in series with the power system and activated by line current. Therefore, in this work, we

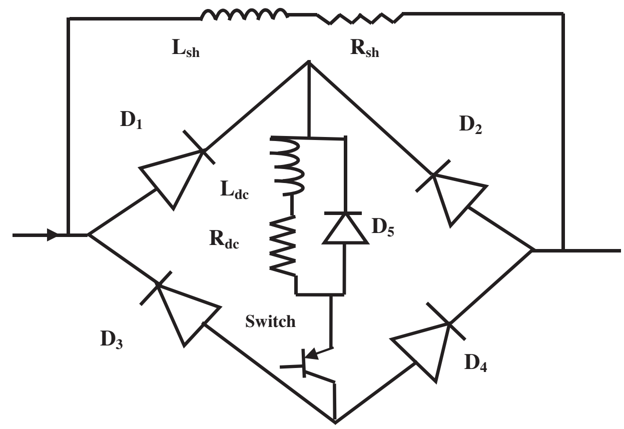

Fig. 1. Bridge type fault current limiter.

choose the TCSC to see the performance of the BFCL. Our main objective is to observe the performance of the proposed BFCL and to check its effectiveness by comparing its performance with other series connected transient stability improving devices.

For demonstrating the effectiveness of BFCL, TCSC and RFCL together with the optimal reclosing of circuit breakers in transient stability enhancement, both balanced and unbalanced permanent as well as temporary faults are considered in the IEEE 30 bus power network and single-machine power network. Simulations are performed by using the MATLAB/SIMULINK software.

2. Control devices

2.1. *Bridge type fault current limiter (BFCL)*

The bridge type FCL described in [10,11] inserts resistance and inductance in the event of a fault, and is used in this work. It has the advantage that it does not need to have the superconductive characteristics for its operation. Thus it reduces the cost. The bridge type FCL basically has two parts as shown in Fig. 1. The bridge part includes a diode rectifier bridge, a small dc limiting reactor (L_{dc}) along with a very small resistor (R_{dc}), a IGBT/GTO based semiconductor switch and a freewheeling diode (D_5). On the other hand, the main part consists of a resistor and an inductor ($R_{sh} + j\omega L_{sh}$) as a shunt branch [10,11].

In normal operation, the IGBT switch remains on and the line current for the positive half cycle passes through D_1, L_{dc}, semiconductor switch and D_4. For the negative half cycle, the line current passes through D_3, L_{dc}, semiconductor switch and D_2. In this operation, the L_{dc} is charged to the peak of the line current and behaves like a short circuit and there is a negligible voltage drop. The freewheeling diode D_5 is used to provide a free route of dc reactor current as soon as the IGBT switch turns off [10,11]. After the removal of the fault, the IGBT switch turns on again and the BFCL resumes its normal operation.

2.1.1. *Bridge type fault current limiter design consideration*

Power systems are nonlinear in nature, and there are always load variations. So, determining the proper values of the shunt impedance is needed. In this work, the proper values of L_{sh} and R_{sh} within the limit are found out by parametric analysis of peak fault current and speed variation. In order to design the rectifier bridge and have parameter analysis, the behavior of BFCL was investigated both in normal and fault conditions. During normal operation, each line carries equal amount of power. To continue the normal operation or to ensure the least disturbance at fault, the BFCL should consume most of the power. The shunt impedance only carries current during fault current limiting mode, during which a